... PERCEPTION WITH SINGLE PICTURES

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ABSTRACT

Single photographic transparencies are shown to produce stereoscopic perception of the recorded scene when displayed with an optical system that produces binocular image disparity. An optical system producing differential illumination and differential aberrations of the binocular images is described.

The conditions leading to single picture stereopsis are reviewed. The contribution of factors like degree and nature of image disparity, color, illumination, sharpness, orientation of contours, depth perception cues, learning, to the observed stereoscopic effect is surveyed.

The proportion of pseudoscopic to true stereoscopic perception of the recorded image, the depth information content of the single image and the possibility to improve performance of optical systems by using knowledge on how the visual system handles information are discussed.

INTRODUCTION

It is well known and understood how to produce a stereoscopic visual simulation of a scene by presenting to the eyes a stereoscopic pair of photographs. These pictures, taken from two positions laterally displaced relative to each other, record most of the retinal information that would be registered by the eyes in a fixed position. When presented to the eyes, such a stereogram simulates the real scene and reproduces the stereoscopic perception of the original.

The presentation of two different images, one for each eye, is so taken for granted as being the only way to produce stereoscopic perception of a recorded scene that it was rather surprising to discover that it can be done also with single images. In other words, not all the visual information imparted by real objects in three-dimensional space is necessary to produce stereoscopic perception. It is the object of this paper to show how, why and under what conditions stereopsis of photographically recorded scenes can be synthesized from monocular information.

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The phenomenon could find application in display and simulation devices, in visual enhancement for detection systems and for plain home slide and movie viewing.

Besides the possible applications (that frequently don't come out to be those envisioned by an author), stereoscopic perception of single images is valuable for the fresh insight it offers into the process of stereopsis.

OPTICAL DISPLAY SYSTEM

The main condition for stereoscopic perception of single pictures is an optical system capable of artificially producing ocular image disparity. One such system found to be very effective is provided by a good quality slide viewer. Its observation section is a large two-lens magnifier of an aperture large enough to contain both eyes, and its illumination section is a diffusing screen illuminated by a concentrated light source (incandescent bulb)-(Fig. 1). The system produces two types of disparity: luminance disparity and geometric disparity.

Any element of the image in the transparency will have a different luminance for each eye because of the anisotropy of the illumination produced by the concentrated source and the diffusing screen. Image elements in the left half of the screen will produce a retinal image of higher illuminance in the left eye and a lower illuminance in the right eye and vice versa. If the concentrated light source is shaped as a vertical line, the left-right luminous disparity will be uniform over the whole height of the picture. A partially diffusing screen (like ground glass rather than opaline plastic) will increase luminous disparity. Luminance diaparity will decrease with distance from light source to screen, the extreme case being collimated light.

Because the optical paths from the image element to each eye are not symmetrical, the aberrations of the optical system will not be the same for the left eye and the right eye image of the same picture element. Thus, the two retinal images of the picture elements possess geometric disparity.

For a symmetric position of the eyes with respect to the axis of the system, image elements situated around the vertical median line of the image do not exhibit any disparity. Due to the integral character of the stereoscopic vision process, however, there is no discontinuity in the stereoscopic aspect of the scene. Various other optical systems for producing retinal image disparity of the same transparency are conceivable, but the one described appears to be the simplest and proved effective in detecting and demonstrating single picture stereopsis.

DISPARITY AND COLOR IN STEREOPSIS

Disparity and color are factors independent on information. They produce stereopsis without any previous training or knowledge from the part of the observer. In real life (by "real life" is meant the experience encountered during the evolutionary process that led to human vision as it is today) disparity of the retinal images of the same object was always produced by the position of the object relative to the eyes. This is why the sense of vision always interprets disparity as produced by relative position in space and "disparity alone

provides the necessary and sufficient stimulus for the emergence of the stereoscopic experience"[1].

A survey of past research on space perception and stereopsis discloses a variety of findings that explains completely the phenomenon of single picture stereopsis and accounts for all the factors involved. Luminance disparity, geometric disparity and color stereopsis were shown to produce stereopsis.

Luminance disparity was produced by a neutral density or a colored filter in front of one eye.

In the Pulfrich stereophenomenon[2] the bob of a pendulum moving in a frontal plane seems to describe an elliptical path, nearer to the observer when moving in one direction, and farther from him when returning. Changing the filter to the other eye reverses the effect. The magnitude of this stereoscopic effect was found to increase with filter density.

The same stereoscopic effect can be obtained substituting the neutral density filter with illumination of one eye (using an "additive filter" as it were)[3].

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In irradiation stereoscopy (4,5) two illuminated white rectangular sheet-like objects in a frontal plane with a black background, when observed with a neutral density filter appear to have rotated each by a small angle about its vertical axis of symmetry.

Stereoscopic depth and stereoscopic acuity are enhanced by use of a colored filter in front of one eye[6].

Geometric disparity with artificial objects was used to investigate stereopsis[7].

The objects are random dot patterns, where the difference between the left and right eye figure consists in the displacement of patches of dots in the two otherwise identical figures. Stereoscopic perception of the displaced part of the figure is produced. The stereoscopic effect is so strong, that a wide range of optical illusions can be reproduced with the "stereo patches" of the random dot figures[8].

The production of stereoscopy by geometric disparity is well known in astronomy, where it is used for rapid identification of changes in the

map of the sky. Two photographs of the same region of the sky, taken at different periods, are observed in a stereoscope. Any new object like a supernova or comet, or an object that changed its place between exposures, will appear as floating in front or behind the plane of the picture.

The same technique is used in the observation of aerial intelligence photographs to detect changes in a scene. It was observed that geometric disparity produced by observing a plane slide with a larger magnifier containing both eyes makes the slide appear to be convex[9].

<u>Color stereoscopy</u> is the second experience independent condition that produces stereoscopic perception of single images. Small luminous objects of different colors appear to be at unequal distances [10]. Colors in the long wavelength part of the spectrum appear usually nearer than the shorter wavelength colors.

The color stereoscopic effect depends also upon the relative luminosities[12].

The color stereoscopic effect is rather striking and, depending upon other information present in the image, tends to either enhance the true stereoscopic perception or to create pseudoscopic effects, where details do not occupy their natural place in stereoscopic space.

"REAL WORLD" SCENES AND DISPARITY

In accordance with sound scientific method, simple elements of the phenomena were isolated for study and this is why previous research on stereopsis deals with simple artificial objects. This approach, albeit the only practically possible, does not always handle satisfactorily the complexity of the real world. A case in point is the visual process where previous experience of the observer plays such an important part.

Inducing binocular disparity for complex objects like photographic, colored and black and white, transparencies of real life scenes will put in evidence the interdependence of the factors involved in stereopsis.

Artificial disparity will always produce some stereoscopic effect, that will be supplemented by the rest of the depth information present in the picture to produce stereopsis.

In many cases, this stereoscopic effect is akin to that produced by pairs of stereograms. The observer sees a stereoscopic simulation of the photographed scene, rather than some stereoscopic distortion of the transparency as an object in itself. The simple objects, or details of objects in the recorded scene appear in their right place in stereoscopic space, as they would with pairs of stereograms.

The stereoscopic effect thus produced varies in intensity and realism, depending on a number of conditions that will be discussed further.

Nineteen typical slides were shown to 37 observers of ages ranging from 25 to 62. All but one of the subjects described the same stereoscopic effects. One subject, who disclosed uncorrected eyesight, different in both eyes, did not discern any stereopsis.

PRODUCTION OF SINGLE PICTURE STEREOSCOPIC PERCEPTION

Luminous and geometric disparity, as well as color stereoscopy where shown to produce stereoscopic perception. There is no indication however in the literature of any factor that would cause true stereoscopic perception.

The single image does not contain stereoscopic information, like true geometric disparity for the left-right eye images of objects, or true luminosity disparity. The stereoscopic perception of the image is produced using artifically produced geometric and luminous disparity. Nevertheless, the scene is perceived in true stereoscopic perspective. This is not violating any conservation law. We are not getting something for nothing.

In the phenomenon of space perception, the stereoscopic cues represent only a small part of the wealth of visual information, present and stored, used by the brain to construct the sensation of visual space. It appears that the rest of the visual information, the depth perception cues combined with artificially induced stereoscopy with its enhancing factors are sufficient to produce a valid simulation of visual space using a single picture. The more cues, the more intense and realistic this perception will be.

A study of stereoscopic effects shown by a number of photographic slides leads to the conclusion that the depth perception cues and the stereoscopy enhancement factors are contributing statistically to the

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stereoscopic effect. Below a certain minimum, all there is left are stereoscopic illusions, with red or orange luminous spots in the image "floating" in the back or in front of it. In the presence of enough cues, at the other extreme, we see a stereoscopic image that could hardly be told from one produced by a conventional stereogram.

The depth cues and the stereopsis enhancement factors are not independent parameters. They reinforce and complement each other in various degrees, according very much to the statistical conditions prevalent in the visual world of the observer.

STEREOPSIS ENHANCEMENT FACTORS

These factors are connected with the technical characteristics of the picture.

Sharpness of focus and contrast were recognised as factors of stereoscopic acuity[13].

Vertical contours are essential in stereoscopic vision[14]. The more vertical contours in a scene, the more marked the stereoscopic effect. Also, stereoscopic acuity is higher for rods than for points.

High <u>retinal illumination</u> increases stereoscopic acuity(15)(16). It should be noted at this point that stereopsis is present both in photopic (cone) and scotopic (rod) vision.

It can be seen that these technical parameters as well as others to be discussed further coincide largely with the desiderata for any good photograph.

DEPTH CUES AND INFORMATION

The accumulation of monocular depth perception cues determines the degree of realism in single picture stereopsis, since these are the information that characterizes the cognitive part of the visual process.

Most depth cues should be called familiarity cues, since they are acquired through a learning process. It is known that depth perception is impaired in unknown surroundings and the dependence of depth cues on cultural background was demonstrated(17,18,19). Monocular depth perception cues contribute to the production of single picture stereopsis on a cumulative basis and can be classified into(20): interposition; size of known objects; association with other objects; perspective of

parallel lines; vertical position in field; foreshortening due to perspective; distribution of light and shadow; aerial perspective.

All these cues are the result of matching the details of an observed scene with the model of the world existent in the observer's mind.

We remarked already that in single picture stereopsis the quantity of information imparted by the cues must be above a certain threshold. In other words, single, too few or too weak cues will produce an ambiguous, unstable or throughout pseudoscopic perception. (E.g., car taillights in a dark scene will appear floating in stereoscopic space, disconnected to the cars themselves.)

The presence of familiarity cues in a single picture is essential for the fidelity of stereoscopic perception. We observed that in all our subjects, stereopsis was the more positive the more explicit the slides, and the more luminous and sharper the picture. For dark or inexplicit details or background, stereopsis was diminished or retarded. In real life conditions, stereopsis depends heavily on secondary cues. Ambiguous or misleading cues were used to

create spatial illusions that were not dissipated by binocular observation. The stereoscopic localization of scene elements was falsified

In case of ambiguous visual cues, the observer can even be conditioned at what depth to perceive the object by conditioning with acoustical stimuli[22].

STEREOPSIS OF COLORED SLIDES

Taking any batch of colored slides representing familiar scenes or subjects and classifying them by the degree of stereopsis, it was observed that the most effective were always the ones on which visual information is clear and obvious. Not so surprisingly, these are the ones that are good from a photographic standpoint also. They are in good focus, there are no overexposed or underexposed details, the elements of the scene are obvious, uncluttered, well detached visually from one another. They have good color contrast and are not ambiguous. The objects present texture; that means there are no large areas unbroken by detail. Or, to better stress the information aspect, the "message" of the picture is clear. It is worth remarking that good conventional stereograms present the same characteristics. In case that

only part of the picture was up to these standards, then only this part induced stereopsis. The rest either did not induce stereopsis, or produced pseudoscopic effects of false perspective, or stereoscopic illusions of objects "floating" in visual space without connection to the scene recorded in the picture.

According to the photographic quality of the picture and to the abundance of cues, weak or strong stereopsis was experienced. For unfamiliar scenes, stereopsis may appear only after a few seconds, when the objects are identified.

Stereopsis with single pictures could facilitate the study of various factors of visual perception. The use of photographs makes the manipulation of the variables more flexible(17).

CONCLUSION

Stereoscopic perception can be reconstituted from artificial image disparity and real depth cues. The intensity and fidelity of the phenomenon is dependent on the quantity of information conveyed by the picture.

Stereoscopic perception with single pictures

stresses the nature of the process of vision as part of a highly integrated and complex information acquisition and processing system. (How complex it is can be inferred from the fact that of all senses it is allocated the largest area on the cerebral cortex.) Vision is more than a sum of image acquisition and processing mechanisms coupled to a computer that interprets the images. We have there a learning system that is working in real time, continuously adjusting and extending its internal model of the world and comparing to it any inputs.

On the more practical side, single picture stereopsis can be used for image enhancement as approached from the visual information acquisition and processing standpoint rather than by what we elect to call "brute force," i.e., enhancement of the energy related parameters like illumination, power, intensity.

Retinal image disparity can be created and the effects of color can be used to intensify perception and discrimination of details in a picture.

Besides its sensitivity to the energy carried by electromagnetic radiation, human vision possesses

sensitivity to information. This "information sensitivity" is much harder to define quantitatively, but is nevertheless there and makes itself obvious in occurrences like the fast identification of spots presenting ocular disparity in image pairs. Visual information sensitivity, if adequately put to use, could improve the performance of many visual systems without need to push the state of the art in their energy collection, transfer and amplification capability.

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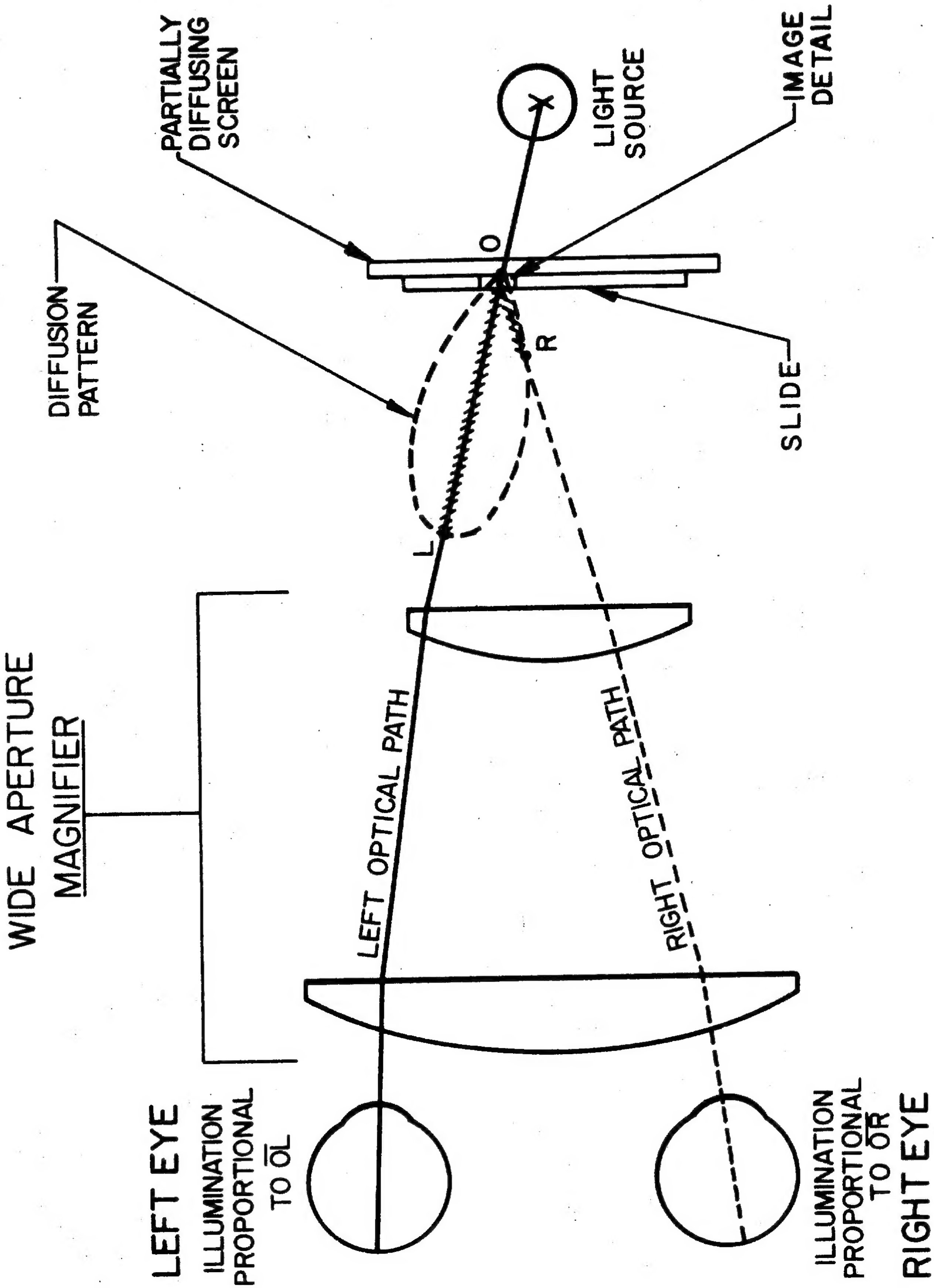
Figure 1

Optical System producing luminous and geometric disparity with a single transparency.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[redacted]

Dear Bob & Paul —

This is the paper [redacted] promised during my phone conversation several months ago (see my memo of 2 Oct).

STAT

I don't think this has any real relevance to you (hence only one copy) but the record is complete —

Regards,

Herb